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The gas proportional scintillation counter/microstrip gas chamber hybrid detector

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Abstract

The gas proportional scintillation counter/microstrip gas chamber (GPSC/MSGC) hybrid detector for X-ray spectrometry is described. The detector uses a CsI-coated microstrip plate placed in direct contact with the gas-filling as the photosensor readout for the GPSC scintillation substituting for the photomultiplier tube (PMT). Usable photosensor maximum gain is limited by optical positive feedback due to the additional scintillation produced in the electron avalanche process at the MSP anodes, in the absence of quenching. A low-photoelectron collection efficiency is achieved in the gas atmosphere, resulting in a scintillation conversion efficiency that is about a factor of 5 lower than that achieved with PMT-based GPSCs. However, energy resolutions of 11% for 5.9 keV X-rays are achieved with this detector.

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1. Introduction

Gas detectors have been widely used for X-ray spectrometry in applications such as astrophysics, high-energy physics and medical instrumentation for their simplicity, ruggedness, large detection area capability and room temperature operation.

In 1988 Oed [1] introduced the idea of replacing the wire grids in conventional chambers by metal microstrips deposited on an insulating substrate, a

microstrip plate (MSP), triggering a new generation of micropattern detectors. An important application of the micropattern technology has been the development of novel photosensitive gas detectors-based on CsI photocathodes. These include MSPs and GEMs, either combined with semi-transparent CsI photocathodes placed few mm apart, or else with a reflective CsI-layer covering the upper part of the microstructure [2–8]. These photon-detectors present an inexpensive alternative to photomultiplier tubes (PMT) with the additional advantages of compactness, low power consumption, the capability of having large sensitive areas, being position-sensitive and operating under strong magnetic fields.

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The concept of a gas proportional scintillation counter/microstrip gas chamber (GPSC/MSGC) hybrid detector has been developed recently [4,8]. A CsI-coated microstrip plate (MSP), placed in direct contact with the gas-filling, substitutes in this detector for the PMT commonly used as the UV-photosensor in GPSCs. This type of detector combines the advantages of both types of detectors, GPSC and MSGC. Additionally, this photosensor is integrated inside the GPSC body, operating directly within the scintillation gas and avoiding the use of a scintillation window that could be expensive and difficult to handle, and that would absorb some of the scintillation. This is a clear advantage in applications where large detection areas and/or high gas-pressures are needed.

In this work we will describe the GPSC/MSGC hybrid detector. Its performance, present limitations and grounds for improvement will be discussed in terms of the photosensor characteristics.

2. Detector description

A typical GPSC/MSGC hybrid detector is depicted schematically in Fig. 1. The GPSC absorption/drift region, 4-cm deep, is separated from the scintillation region by a stainless-steel grid (80 μm diameter wire with 900 μm spacing), G1, while the scintillation region, 1-cm deep, is delimited by G1 and by the MSP (CERN MS-4 model: 10- μm wide anodes, 80- μm wide cathodes with 55- μm gap, deposited in a Desag D263 glass substrate). The CsI-coated MSP serves simultaneously as the GPSC collection grid for the primary electron cloud, the photosensor for the GPSC VUV-scintillation, and the amplification stage for the photoelectrons. While the upper region, d_1 , operates as the uniform-field scintillation region of a conventional GPSC, the region d_2 (<50 μm) functions as a standard MSGC.

A $\sim 500\text{-nm}$ thick layer of high-purity CsI is vacuum deposited onto the surface of the MSP. Special care has to be taken to avoid water contamination of the CsI film: the MSP is heated

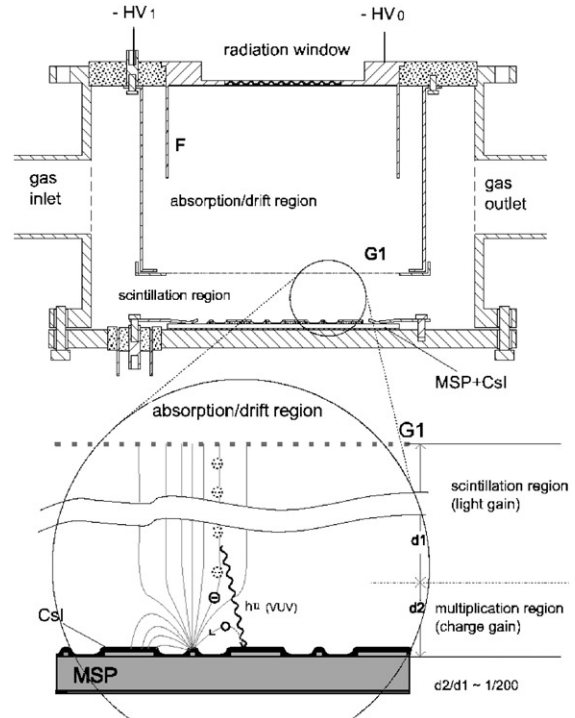


Fig. 1. Schematic of the GPSC/MSGC hybrid detector.

at temperatures of about 100°C during 1 h before CsI evaporation, the exposing time of the CsI film to air is about 10 min, and the CsI film is heated under vacuum at about 80°C for 24 h after the CsI-covered MSP has been placed inside the detector [9,10].

Since the detector pulses are taken from the MSP anodes, a positive voltage, V_a , of few hundred volts is applied to the anodes while the MSP backplane and the cathodes are maintained at ground potential. This way, the detector radiation window and the focusing electrode F, as well as the G1-grid and its holder electrode, must be maintained at negative high voltage of several kV, $-HV_0$ and $-HV_1$, respectively, to produce the suitable electric fields for the GPSC operation. The electric field in the drift region is determined by the voltage difference between $-HV_0$ and $-HV_1$, while $-HV_1$ determines the electric field in the scintillation region. The electric field above the cathode strips is determined by both the anode strips voltage and the G1 voltage.

3. Detector operational characteristics

The X-rays interact in the GPSC absorption region and the resulting primary electron cloud drifts towards the scintillation region under the influence of a weak electric field, below the gas scintillation threshold. In the higher electric field of the scintillation region (lower than the gas ionisation threshold) electron–atom collisions produce VUV-scintillation photons, from which the ones incident on the CsI induce the emission of photoelectrons from the MSP active areas, the cathode strips. The photoelectrons drift towards the anode strips producing charge avalanches under the intense electric field.

The volume resistivity of the CsI coating is similar to that of semi-conducting glass substrates used for high-rate MSPs applications [11]. Consequently, the presence of the CsI coating does not compromise the operation of the MSP; instead it results in a reduced substrate charge built-up.

Fig. 2 depicts a typical detector relative pulse amplitude and energy resolution as a function of the anode voltage, V_a , for 5.9-keV X-rays and for Xe gas-filling, while maintaining constant the E/p (the electric field E divided by the gas pressure p) in the drift and in the scintillation region. An exponential function (solid line) is superimposed on the experimental results. For comparison purposes, the relative pulse amplitude for a GPSC coupled to an independent MSGC with the CsI-

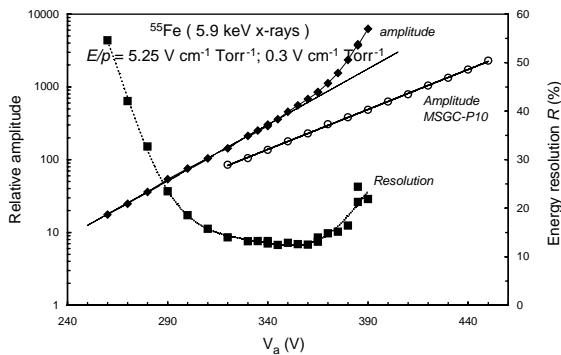


Fig. 2. Hybrid detector relative pulse amplitude and energy resolution as a function of the anode-to-cathode strips voltage, V_a , for a constant reduced electric fields in the drift and scintillation region, as well as the relative amplitude for a GPSC coupled to an independent MSGC with P10-filling.

MSP operating in a quenched gas (P10) is also depicted.

The photosensor gain follows the characteristic exponential variation of charge avalanche processes in MSGCs. Above a certain V_a , the gain diverges from its initial behaviour, due to optical positive feedback, as a result of the additional scintillation produced in electron avalanches, in the absence of quenching, leading to a faster gain increase.

Detector energy resolutions of about 11% have been obtained for 5.9 keV X-rays. Although this energy resolution is not as good as what is achieved with PMT-based GPSCs (8%) it is better than those of other xenon detectors-based on charge amplification. The electronic noise in the low-energy limit reaches values below 250 eV.

The optical positive feedback limits the maximum useful MSP gain, by limiting V_a , since positive feedback introduces additional statistical fluctuations that lead to a degradation of the detector energy resolution. Detector energy resolution degrades above positive feedback gains of about 1.1 [12]. The GPSC coupled to an independent MSGC with the CsI-MSP operating in a quenched gas, like P10, is not affected by positive feedback and presents pulse amplitudes that are about 50 times larger, energy resolutions about 10% and energy noise tails below 60 eV [8]. This performance is somewhat better than that of the hybrid detector, though it may not be decisive if large area and/or high-pressure detectors are needed.

Hybrid detectors with MSP designs presenting different cathode-to-anode gap and cathode strip widths have been studied [7]. It was shown that optical positive feedback is more intense for larger cathode strips while a dependence of optical feedback on the anode-to-cathode gap is not noticeable.

Fig. 3 depicts the detector relative pulse amplitude and energy resolution as a function of E/p in the scintillation region for different gas-fillings (Xe-100%, Xe-30% Ar and Xe-80% Ar), keeping E/p in the drift region and the photosensor gain constant. The solid curves serve only as a guide to the eye. The experimental results reveal the approximately linear trend above about

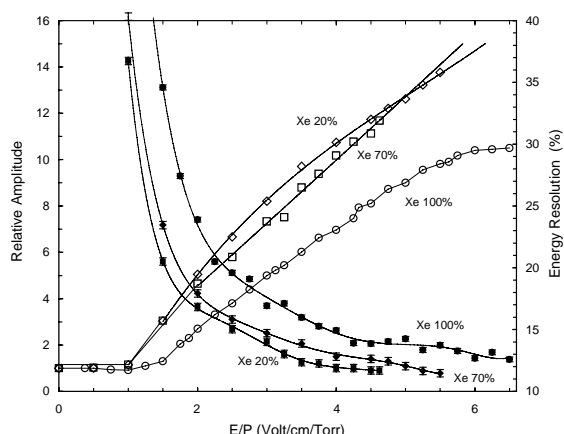


Fig. 3. Detector relative pulse amplitude and energy resolution as a function of the reduced electric field in the scintillation region for different Xe–Ar mixtures using a constant photosensor gain (at optimum value for each mixture) and a constant reduced electric field in the drift region ($0.3 \text{ V cm}^{-1} \text{ Torr}^{-1}$). The solid curves serve only as a guide to the eye.

$1 \text{ V cm}^{-1} \text{ Torr}^{-1}$, characteristic of the GPSC secondary scintillation yield. Below the gas scintillation threshold pulse amplitudes become constant, being the pulse height due to the charge amplification of primary electrons only. These results show that the hybrid system behaves as a GPSC rather than a MSGC and that the scintillation amplification stage results in amplification gains that can be larger than 10 and in reduced statistical fluctuations, relative to the MSGC operation. The electronic noise-tail at low energies limits the minimum detectable X-ray energy, which decreases with increasing xenon concentration, being about 800 eV for pure argon, around 600–500 eV for xenon concentrations between 10–70%, and about 250 eV for pure xenon.

This gain is small compared to what is achieved with PMT-based GPSCs, being the reduced light conversion efficiency the major drawback of this photosensor. From the scintillation gain (~ 9) and/or the energy resolution ($\sim 11\%$) one can estimate the number of photoelectrons per primary electron that undergo amplification in the photosensor to be about 4 [13,8], while with PMTs this number is above 20. A limiting factor of this performance is the poor photoelectron extraction and transmission from the cathode strips to the

avalanche region around the anode strips. This is due to backscattering of the photoelectrons in the xenon atoms. Thus, lower-Z gases, such as xenon–argon mixtures, present more favourable photoelectron transmission efficiency and improve the performance of the hybrid detector [12]. However, this improvement is limited by the decrease of V_a that can be achieved in the MSP prior to the onset of positive feedback as the xenon concentration decreases (e.g. 360, 300 and 220 V for Xe-100%, Xe-30% Ar and Xe-80% Ar, respectively).

4. Conclusions

The GPSC/MSGC hybrid detector attains energy resolutions of 11% for 5.9 keV X-rays. The electronic noise in the low-energy limit reaches values below 250 eV. The CsI-MSP photosensor operating in xenon presents scintillation conversion efficiencies ~ 5 lower than PMT-based GPSCs; the low-photoelectron collection efficiency is the main factor responsible for this difference. Optical positive feedback limits photosensor gain due to additional scintillation produced in the electron avalanches at the MSP anodes. Still, the resolution achieved is better than with charge amplification-based detectors.

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